Concentration, Regulation, and Maize Biotech Research:
An International Perspective

David Schimmelpfennig, Carl Pray, and Margaret Brennan

Introduction

Maize is the crop that has received more attention from biotechnology researchers than any other crop. Maize made up 37% of field trials of genetically engineered (GE) crops in the U.S. and Canada and 36% of field trials in developing countries (Courtmanche, Pray, and Brennan 1999). Insect-resistant maize, herbicide-tolerant maize, and maize with both traits covered 11 million ha worldwide in 1999 – more than any genetically engineered crop except soybeans. Almost all of the GE maize seed sold commercially and most of the maize biotech research is by a few major Life Science companies that have their main maize research programs in the U.S. This raises a number of questions for policy makers outside the U.S. Does entry of Life Science companies in a country stifle research and close out the possibility of competition by local firms? Does public sector maize research encourage or discourage private biotechnology research by Life Science companies and/or local companies? Does concentration of research in a few companies – local or foreign – reduce the amount of biotech research?

This paper attempts to look at the role of life science firms, industry concentration, and public research in stimulating private biotechnology research. The next section reviews the stylized facts about world maize production and the spread of biotechnology. The following section proposes a model of biotechnology research and tests it using the available data on maize biotechnology in 9 countries. The last section examines some of the implications for policy makers.

Maize Production, The Spread of Transgenic Maize, and Industry Consolidation

The twenty largest producers of maize in 1999 are listed in Table 1. Over 40 percent of world maize is produced in the U.S. followed by China with 22 percent. The exports and imports of this group are listed in the next two columns. The U.S. accounts for over half of exports while Europe, Japan, Mexico, and China are among the major importers.

GE maize varieties have spread rapidly in the U.S. They were first planted commercially in 1996 and were used on 10 million ha in 1999. However, they have not spread as

1

rapidly elsewhere. About a million ha are grown in Canada, Argentina, South Africa, Spain, and France. (James 1998). Argentina and South Africa are the only countries outside the U.S. where GE maize use is growing rapidly.

The testing of GE maize in government approved field trials has taken place in about 30 countries. In most countries there have been only a few trials or the details are not made public. In 11 countries outside the U.S. a time series of maize field trials is available. These countries, listed in Table 2, include all of those in which GE maize is being grown commercially.

In the U.S. and many other countries, maize research has attracted more agricultural research dollars from the private sector than any other crop. Large seed firms like Pioneer Hi-Bred spend more than $100 million annually on maize research. Maize has also attracted more biotechnology research than any other crop. More than a third of all U.S. plant biotech research as measured by field trials has been on maize[1]. Some of the initial U.S. private biotechnology research was conducted by small biotech start-ups such as Cetus and Genentech. The perception of these companies was that agricultural biotechnology would come quickly to the market and that earnings from agriculture could be used to fund biotech research on new pharmaceuticals, which were expected to take longer to develop because of greater regulation in the pharmaceutical industry. However, by 1991 when the first large groups of GE maize field trials were conducted in the U.S., most of the trials were carried out by the major seed firms - Pioneer, DeKalb, Northrup-King, and Garst. Agricultural chemical firms already owned some of the seed companies – Northrup-King and Garst for example.

Throughout the 1990s many of the major chemical/pharmaceutical companies sold off their bulk chemicals and other low margin businesses to concentrate on "Life Sciences" – pharmaceuticals and agricultural biotechnology. They used the money from these sales and the increasing value of their shares to finance the acquisition of small biotech companies and seed companies, to invest in biotech research, and to transform themselves into "Life Science"[2] firms (see Table 3). As a result the major companies – DuPont, Monsanto, Aventis, and Novartis – now conduct about two thirds of the maize field trials in the U.S. (last column Table 2). Smaller seed companies continue to do some trials along with a few biotech start-ups that seem to be concentrating on using corn to produce pharmaceuticals.

Maize biotechnology was introduced in most countries by private firms. Which firm introduced maize biotechnology in a new country depended on the structure of the seed industry in that country. In European countries that already had strong local seed firms – France, Spain, and the Netherlands - local companies led the way and then the Life

---

[1] Many countries now have biosafety committees to which companies and government research institutes must report whenever they wish to test a new genetically engineered combination of genes and crop variety. The field trials are available for many countries on government websites. We have counted the number of field trials that are conducted by crop and company for a number of countries. This number, referred to as field trials, is the main measure of private biotechnology research in this paper.

[2] Life sciences include the biological sciences, which deal with health, food, and agriculture.

Science companies came in through subsidiaries that were already in the seed business there. In the late 1990s, Life Science companies expanded their research into more countries and bought some of the smaller companies. In countries where the major seed firms and Life Science companies already had a major presence in the seed industry – Argentina, Canada, South Africa, Italy – these companies did the first testing of transgenic maize and conduct almost all of the field trials today. The last column of Table 2 shows the dominance of Life Science companies in these countries.

The only biotech start-up that played an important role in spreading maize input traits in any of these countries was a Belgian company, Plant Genetic Systems (PGS), which was purchased by Agrevo in 1997. PGS is particularly important in Europe and Japan. In 1999 a few new biotech companies started doing maize field trials in the U.S. and Europe, but they seem primarily interested in maize as a medium for producing pharmaceuticals.

Model

Our theoretical framework for this international system of maize research goes back at least to Arrow (1962) who argued that the payoff to a successful firm in an R&D race should depend on the structure of the market for its innovation. Other authors, like Phillips (1971), have shown that the nature and structure of R&D might feed back and influence the structure of the market for resulting innovations. In Schumpeter's writings on innovation, concentration in markets leads to more R&D and influences market structure through "creative destruction." In this paper, we empirically test a Schumpeterian model in which market structure and R&D are jointly and endogenously determined (Levin and Reiss 1984). R&D is a function of market size, appropriability and technological opportunity; and concentration is a function of R&D.

To test the impact of concentration on research intensity, our principle goal, we have identified variables that measure concentration and research, and other important variables that influence research intensity. The variable names and sources of the data are listed in Table 4. Research intensity in corn biotechnology, R, is measured by field trials of genetically engineered maize in the ten countries outside the U.S. listed in Table 2, divided by profitability of maize sales in each country, to control for market size.

Firms' expectations about the size of the market will be based on the size of the markets for products that they hope biotech markets will replace – in this case conventional hybrid maize seeds and pesticides. In some cases firms must estimate the size of entirely new markets - for example, the control of European corn borers which previously could not be controlled by pesticides. In the latter case, expected markets might depend on how widespread pest attacks are and how much damage is done. However the only factor, which goes into firms' calculations of expected profit for which we have data, is the value of seed sales minus the cost of the R&D.

Second, we control for factors ($\mathbf{Y}$) affecting γ, or appropriability. Firms' expectations about what share of the market they can capture will depend on the legal structure of

intellectual property rights in the country, the physical ease of copying the invention, and the ability of the firms to stay ahead of competitors. In addition, monopoly power arising from factors other than intellectual property rights and staying ahead of competitors can also increase firms' ability to capture a share of the market. In the countries in this sample maize is a hybrid crop which means that it is technically difficult for farmers to pirate the seed. However, companies do feel it is important to protect their breeding techniques, inbred lines, and genes using utility patents in countries where this is possible.

Second, we control for a vector of factors ($\mathbf{X}$) that shift technological opportunity α. Some of these factors are crop specific public research and plant breeding, crop specific transformation possibilities, and the exploitation of economies of scale and spillovers of public goods. Firms' expectations about technological opportunity is likely based on the cost of research and the probability of developing and commercializing a new product. This expectation will in turn depend on the cost of research inputs, and the time and effort needed to develop a commercial product. Technological opportunity to improve corn in a specific country will be influenced most greatly by public sector research in the country. Public research provides genes, corn germplasm, scientists and labs that can do contract research for the private sector, and information about the most effective crop management techniques. Also, if the firms are Life Science companies that already own a transgenic hybrid that has been developed elsewhere in similar agro-climatic conditions, then the technological opportunity in the new market may be high with low associated costs. Biosafety regulations and varietal registration regulations can add substantial additional development costs and increase the risk the research may not pay off.

The amount of public research and past research success may also drive changes in agricultural industry structure. The main incentive for expansion and concentration is to spread-out the sunk cost of research, especially the large investments that are required to do basic biotechnology research. The growth of "Life Science" giants may have resulted from a desire to spread the cost of basic biotechnology research over as large a share of the seed and plant protection industry as possible, to span as many industries as possible, and as large a geographic area as possible.

Finally, we control for factors that would affect expected sales of biotech products other than current sales[3] (approval of first biotech crops, first sales of biotech products, outbreaks of pests, sales of substitutes, and development of substitutes). Factors other than in-house research that might affect mergers and the level of consolidation include exogenous breakthroughs in science (basic biotechnology research, and genomics), intellectual property rights, legal risks, market opportunities (synergies from "cross-selling"), and economies of scale in marketing and research.

---

[3] USDA seed data stops in 1996 and is interpolated for 1997 and 1998, the years in which genetically engineered soybeans, corn and cotton spread widely. Thus, the value of seed variable does not pick up the increased cost of seed due to the inclusion of the technology fee in the seed price or the addition of a separate technology fee. This means we must include a separate variable to capture the spread of biotech – the percentage of the crop covered by genetically engineered varieties.

The firms in the theoretical model are profit maximizers, with costs that are decreasing, convex functions of both own and industry R&D. There is some evidence that agricultural input markets are oligopolistic with free-entry, and that individual firms choose output, and their level of spending on R&D and advertising (Barton 1998). Three structural equations, corresponding to the first-order conditions of the profit maximizing firms, simultaneously determine the three choice variables for symmetric industry equilibria:

1. $1/n = \varepsilon(R+S)$,

2. $R/(1-(R+S)) = \alpha + \gamma\theta/n$,

3. $S = \varphi/\varepsilon n$,

where n is the number of firms in each input market, so 1/n is the Herfindahl index of concentration (H); R and S are input market R&D and advertising intensity respectively; and ε is the price elasticity of demand faced by the firms.

In the second equation, α is firm elasticity of unit cost with respect to own R&D, which comes from the assumption that R&D is focused on cost reducing innovations. This represents technological opportunity or the productivity of research. Also in the second equation, γ is the elasticity of unit cost with respect to input industry R&D holding own R&D constant. This elasticity is a measure of the extent to which research by other firms, spills over to affect the cost to the individual firm. The spillover will be related to the technologies involved and to available intellectual property rights. Finally, θ represents Cournot conjectural variations concerning the response of input industry R&D to a change in one firm's R&D level. In the third equation, φ is the input market advertising elasticity of demand.

Dasgupta and Stiglitz (1980) show that the profit of each firm in an industry in a similar model is zero with entry and exit. Levin and Reiss (1984) also show that with Cournot conjectures in output and advertising, equilibria exist under a wide range of parameter values for these three conditions. Since the input market elasticities, α, ε, γ, and φ, do not have to be constant in this model, additional structure must be imposed to estimate the model empirically. Specifically it is assumed that both the underlying cost and inverse demand functions have constant elasticities. After taking natural logs of the first structural equation and dropping the third equation for lack of data, the basic empirical equations are:

4. $\qquad$ $\text{Log } H = \text{constant}_1 + \beta_1 \log(R) + e_1$

5. $\qquad$ $R = \text{constant}_2 + \beta_2 \, \alpha + \beta_3 \, (\theta\gamma H) + e_2$

where R is profit intensity, $\beta_{1,\dots,3}$ are estimated coefficients, and the $e_{1,2}$ are residual errors. Equation 5 is not in logarithms so the equations can be estimated jointly as a linear simultaneous system.

There are several approaches available for instrumental variable estimation of panel data. Baltagi (1981) shows that one-way error components three-stage least squares reduces to one-way error components two-stage least squares (EC2SLS) when the errors in equations 4 and 5 are uncorrelated with each other. This appears to be the case as we show in the results section. These two techniques are, respectively, members of the wide asymptotic equivalence class of full and limited information maximum likelihood estimators. Since these latter techniques have the most desirable theoretical properties, and simple EC2SLS is a member of the limited information class, we estimate the system with EC2SLS.

The variables to be used and their sources are listed in Table 4. We estimate the model using time-series, cross-sectional data on maize field trials from 1991 to 1999 in 9 countries of which two are developing countries. These countries were chosen because they include all of the countries where transgenic maize is being grown commercially and where maize biotech research as measured by field trials has been conducted over a fairly long period of time.

The variable that we use to measure appropriability is the number of biotech patents on maize. Firms will not patent in countries where the patent system is too weak to be useful. In Europe, in particular, there was a decision that plant varieties would be protected by plant breeders rights, a somewhat weaker form of legal intellectual property protection than utility patents that are available in the United States. In addition, there has been a long debate over whether genes can be patented. It was not until 1999 that the European Union decided that they could be patented, a finding that is now being challenged in court. We had to drop Argentina from our sample because we could not get data on maize patents in Argentina.

The technological opportunity variable is the number of published papers on maize by country of author institutional affliation, as abstracted in CAB Abstracts. Concentration is measured as one divided by the number of firms doing maize field trials in each country. If all firms are of equal size this is equivalent to the Herfindahl index of concentration.

Results

The result from estimating the concentration equation (5) (shown in Table 5) by EC2SLS (including group dummy variables) and 2SLS (without group dummies) indicates that concentration and research intensity are positively related to each other. The Akaike Information Criterion selects the EC2SLS formulation, but the result is the same with or without individual constants. These coefficients are elasticities, so a one-unit increase in research intensity, arising from an additional field trial or a one-unit decrease in sales (in $ millions), indicates a 50% increase in concentration, or a drop in the number of firms, for example from 4 to 2.6.

The result from estimating the R&D equation (Table 6) indicates that technological opportunity, measured as a five year lag of public sector research, has a small, positive effect on research intensity and is significant at the 94% level. This is as expected with public research indicating differences in the overall level of technological opportunity across countries. The appropriability variable comes out relatively large, positive and significant. The more value companies place on patenting in a country, and the more they perceive they will be able to avoid technological spillovers in a country, the more research they do. For this second equation, the Adjusted R-squared statistics strongly suggest the specification with group dummy variables (EC2SLS). The average simple correlation between the residuals from the two EC2SLS specifications is only -0.04.

Conclusions

The empirical results indicate that:

1. Concentration of research in a few Life Science companies is positively related to maize biotechnology R&D intensity across the countries in our sample.

2. Lagged public sector maize research has stimulated private biotechnology research in these countries by increasing technological opportunity.

3. Countries, in which companies have more confidence in the biotechnology patent system, also have more private biotechnology research.

References

Arrow, K.J. 1962. Economic Welfare and the allocation of resources for invention. In The rate and direction of inventive activity: Economic and social factors, ed. R.R. Nelson. Princeton: Princeton University Press for the National Bureau of Economic Research.

Baltagi, B.H. 1981. "Simultaneous Equations with Error Components," *Journal of Econometrics* **17**:189-200.

Barton, J. 1998. "The Impact of Contemporary Patent Law on Plant Biotechnology Research". In S.A. Eberhardt, H.L. Shands, W. Collins, & R.L. Lower (Eds.), *Intellectual Property Rights III, Global Genetic Resources: Access and Property Rights*. Madison, WI:CSSA.

Courtmanche, A., Pray, C.E. and Brennan, M. "The Importance of Policies and Regulations in the International Spread of Agricultural Biotechnology." At Conference on the Shape of the Coming Agricultural Biotechnology Transformation: Strategic Investment and Policy Approaches from an Economic Perspective. Rome, Italy. June 17-19, 1999.

James, Clive. 1998. "Global Review of Commercialized Transgenic Crops: 1998" International Service for the Acquisition of Agri-biotech Applications (ISAAA) Briefs, and updates to 2000.

Levin, R.C., Reiss, P.C. 1984. Tests of a Schumpeterian Model of R&D and Market Structure, ch. 8 in Z. Griliches (ed.) R&D, Patents, and Productivity. Chicago: The University of Chicago Press.

Phillips, A. 1971. Technology and market structure: A study of the aircraft industry. Lexington, MA: Lexington Books.

Table 1. Maize Production, Imports and Exports 1998.

Country	Production	Major Exporters Mtons	Major Importers
World	604,400,398	75,021,553	71,696,256
U.S.A.	247,943,008	42,125,446	300,861
China	133,291,617	4,686,666	5,008,533
Brazil	32,503,600	22,234	1,728,903
Mexico	18,476,410	231,204	5,211,863
France	15,204,000	7,979,443	242,915
Argentina	13,700,000	12,442,471	8,972
India	10,783,000	12,000	0
Indonesia	10,058,609	624,942	313,463
Italy	9,030,855	149,198	602,919
Canada	8,670,100	258,705	1,215,889
Romania	8,623,370	388,847	5,634
South Africa	7,693,000	844,000	128,682
Hungary	6,143,270	2,108,720	3,352
Yugoslavia	5,600,000	118,929	11,195
Egypt	5,430,492	976	3,042,914
Nigeria	5,127,000	NA	NA
Thailand	4,986,420	122,713	230,987
Spain	4,264,700	174,331	2,616,384
Philippines	3,823,184	177	470,032
Germany	2,781,464	359,387	946,463

Source: FAO website (WWW.FAO.ORG)

Table 2. Maize Biotechnology Use and Research in Sample Countries

	Maize Production 1999	Area of Transgenic Maize 1999	Maize Publica-tions 1993-97	First Maize Field Trials	First Transgen-ic Maize Planted	No. of Maize Field Trials		Field Trials by Life Science Firms
	(million mt)	(1,000 ha)				1998	1999	% of Total 1999
US	247.9	10,300	3391	1991	1996	459	373	67
Large Europe								
France	15.2	1	231	1992	1998	30	28	57
Italy	9.0	0	200	1992	not yet	14	10	100
Spain	4.3	30	105	1993	1998	16	15	93
Canada	8.7	380	246	1991	1996	3	NA	100
Small Europe +Japan								
Germany	2.8	0	215	1995	not yet	3	1	100
Belgium	0.2	0	33	1992	not yet	2	1	100
Nether-Lands	0.1	0	76	1991	not yet	0	0	0
Japan	0.0	0		1995	not yet	3	4	100
Developing								
Argentina	13.7	260	92	1991	1998	39	41	83
South Africa	7.7	90	100	1994	1998	12	30	93

Sources: Production FAO; Area GE maize, James personal communication 2000; Publications CAB Abstracts; Field trials Rutgers Field trial database; Date commercial GE maize James 1999; Number and concentration of field trials calculated from Rutgers database.

Table 3. Mergers and Acquisitions in the U.S. and European Agricultural Chemicals, Biotechnology, Seeds, and Food/Feed Industries

	Agricultural Chemicals	Biotech	Seeds	Food/Feed
DuPont		Alliances with Human Genome Sciences (1996) Curagen (1997)	Pioneer (1997) (20%) Hybrinova (1999) (France) Bought other 80% of Pioneer (1999)	Quality Grain (1998 Joint venture with Pioneer), Protein Technologies (food), Cereal Innovation Centre UK
Monsanto (Announced merger with Upjohn-Pharmacia 2000)		Agracetus (1995) Calgene (1996) Ecogen (13%) Millenium Pharmaceutical (Joint venture for crops genes)	DeKalb (1996) Asgrow (1997) (corn and soybeans) Holden's Foundation Seeds (1997) Cargill International Seeds, Plant Breeding Intl. (1998) Delta and Pineland (Alliance 1994)	Cargill (1998) Joint venture feed and food Monsanto has food brands like Nutrasweet
AgrEvo (Aventis)	Hoechst & Schering (1994) Hoechst & Rhone-Poulenc (1999) Merger to create Aventis	Plant Genetic Systems (1997) PlantTec	Nunhems, Vanderhave, Plant Genetic Systems, Pioneer Vegetable Genetics, Sunseeds (1997) Cargill U.S. Seeds (1998)	
Rhone-Poulenc (Aventis)	Hoechst (1999) Merger to create Aventis		Alliance with Limagrain which owns Nickersons, Vilmorin, Ferry Morse	
Novartis (Syngenta summer 2000)	Ciba-Geigy and Sandoz (1996) Merger Merck (1997) Buys pesticide business for $910 mil. Announced Merger with AstraZeneca's Ag. Chemicals Dec.1999.		1996 merger brings together Northrup-King, S&G Seeds, Hilleshog, Ciba Seeds, Rogers Seed Co.	Owns Gerber Foods Joint venture with Quaker Oats on nutraceuticals 2000
Astra Zeneca (Syngenta summer 2000)	Announced Merger with Novartis agricultural products Dec.1999.	Mogen International N.V. (1997) Incyte Pharmaceuticals (1996 for pharmaceuticals, 1998 for plants) Alliance with Japan Tobacco on Rice (1999)	Advanta (merger of Zeneca seed and Vanderhave 1996) (owns Garst Seed Co., AgriPro Seeds, AgriPro Wheat, Interstate Seeds in U.S.)	
Dow Chemicals	(1997) Dow purchases Eli Lilly's 40% share of Dow Elanco for $900 million.	Mycogen (1996) Ribozyme Pharmaceuticals Inc.	Mycogen buys Agrigenetics (1992) United AgriSeeds becomes part of Mycogen (1996)	

Table 4. Variables for Model of Spread of Corn Biotechnology.

Variables	Description of Variable	Source(s) of data
R Private corn biotech research	Corn field trials/revenues from seed sales	Field trials OECD/Biotrak website & Individual Government websites. Seed sales calculated from FAO area data and CIMMYT seed rates and prices.
γ Appropriability/ Spillover	Number of biotech patents on maize.	Derwent biotechnology index
α Technical Opportunity	Amount of public sector agricultural research as measured by the number of maize biotechnology publications which had an author working in the country.	CAB Abstracts, CAB International, United Kingdom
	US Public investments in maize research	USDA CRIS database
H Concentration	1/number of firms conducting field trials *	USDA/APHIS OECD/Biotrak website Government websites Personal communications

* Assuming all firms of equal size this is equivalent to the Herfindahl Index.

Table 5   Parameter Estimates: Concentration Equation (t-ratios in parentheses)

Variable	2SLS without Group Dummy Variables	2SLS with Group Dummy Variables (EC2SLS)
LOG Research Intensity	0.50	0.51
	(9.30)*	(8.01)*
CONSTANT	-1.10	__
	(-0.003)	
Adjusted R-squared	.66	.62
Akaike Info. Criteria	18.42	18.63

* Significant at 99% confidence level.

Table 6   Parameter Estimates: R&D Equation (t-ratios in parentheses)

Variable	2SLS without Group Dummy Variables	2SLS with Group Dummy Variables (EC2SLS)
PATENTS	13.35	6
Per firm	(4.72)*	(2.00)**
PUBLICATIONS	0.003	0.005
Lagged five years	(1.17)	(1.94)
CONSTANT	12.50	__
	(0.71)	
Adjusted R-squared	.22	.42
Akaike Info. Criteria	26.04	25.83

* Significant at 99% confidence level.
** Significant at 95% confidence level.